Individual Model Post-Processing Bias Corrections in a Stationary Climate

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Local corrections are done separately by location (grid point), target season, and lead time. The first 3 corrections below are local, the 4th is not.

1. Correction of bias of the mean

2. Correction of bias of interannual variability (amplitude) of ensemble mean forecast

   Definition of “correct” variability, relationship with probabilistic reliability and hindcast RMSE

3. Correction of bias of the ensemble spread (calibration)

4. Correction of spatial anomaly pattern (e.g. placement)

1. Correction of bias of the mean

$$Fct_{corrected} = Fct - (\overline{Fct - Obs})$$

2. Correction of interannual SD of *ensemble mean* forecast

The interannual SD of one member should be same as SD of obs. But, if the correlation between hindcasts and observations is *cor*, the correct interannual SD of the ensemble mean forecasts is

$$SD_{fct} = (cor)\,(SD_{obs})$$

This SD minimizes RMSE of the ensemble mean forecasts.

SD_{fct} = (cor) (SD_{obs}) for ensemble mean forecast

When there is no predictability (cor = 0), interannual SD of ensemble mean forecast should be 0. While this would be true for infinite ensemble size, for finite ensemble size cancellation of noise is incomplete and SD would be

$$SD_{fct} = \frac{SD_{obs}}{\sqrt{n}}$$

where n is the ensemble size.

When cor > 0, within a “perfect” model (disregarding obs), SD_{fct} is larger:

$$SD_{ensmean} = SD_{member}\sqrt{\frac{1}{n} + cor\frac{n-1}{n}}$$

3. Correction of ensemble spread (calibration)

The ensemble spread, expressed as the SD of the forecasts across ensemble members, should be related to the RMSE with respect to observations as:

$$Spread = RMSE$$

The RMSE, in turn*, if forecasts and observations are normally distributed*, should equal the standard error of estimate (SEE), based on cor between ensemble mean forecasts and obs:

$$RMSE = SEE = SD_{obs}\sqrt{1 - cor}$$

When cor=0, then SEE and RMSE equal SD_{obs} and the spread should also equal SD_{obs}.

Two ways to treat the model ensemble spread:

1. Correct (calibrate) the spread so it equals the RMSE of the ensemble mean forecasts with respect to observations. This requires multiplying the anomalies of each member, relative to the ensemble mean, by the factor that changes the spread accordingly.

2. Ignore the spread and use $SEE = SD_{obs}\sqrt{1-cor}$ as the equivalent, to form a Gaussian forecast pdf straddling the amplitude-corrected ensemble mean forecast.

If details of the forecast distribution (e.g., bumps, asymmetries) by the members are seen as meaningful (real), choice 1 is preferred.
Assuming forecast amplitude correction, use of either 1. or 2. makes the forecast pdf probabilistically reliable.

Logical order of local bias corrections (done on each ensemble member, per grid point, target season, lead time)

1. Correction for mean bias, based on bias of ALL members

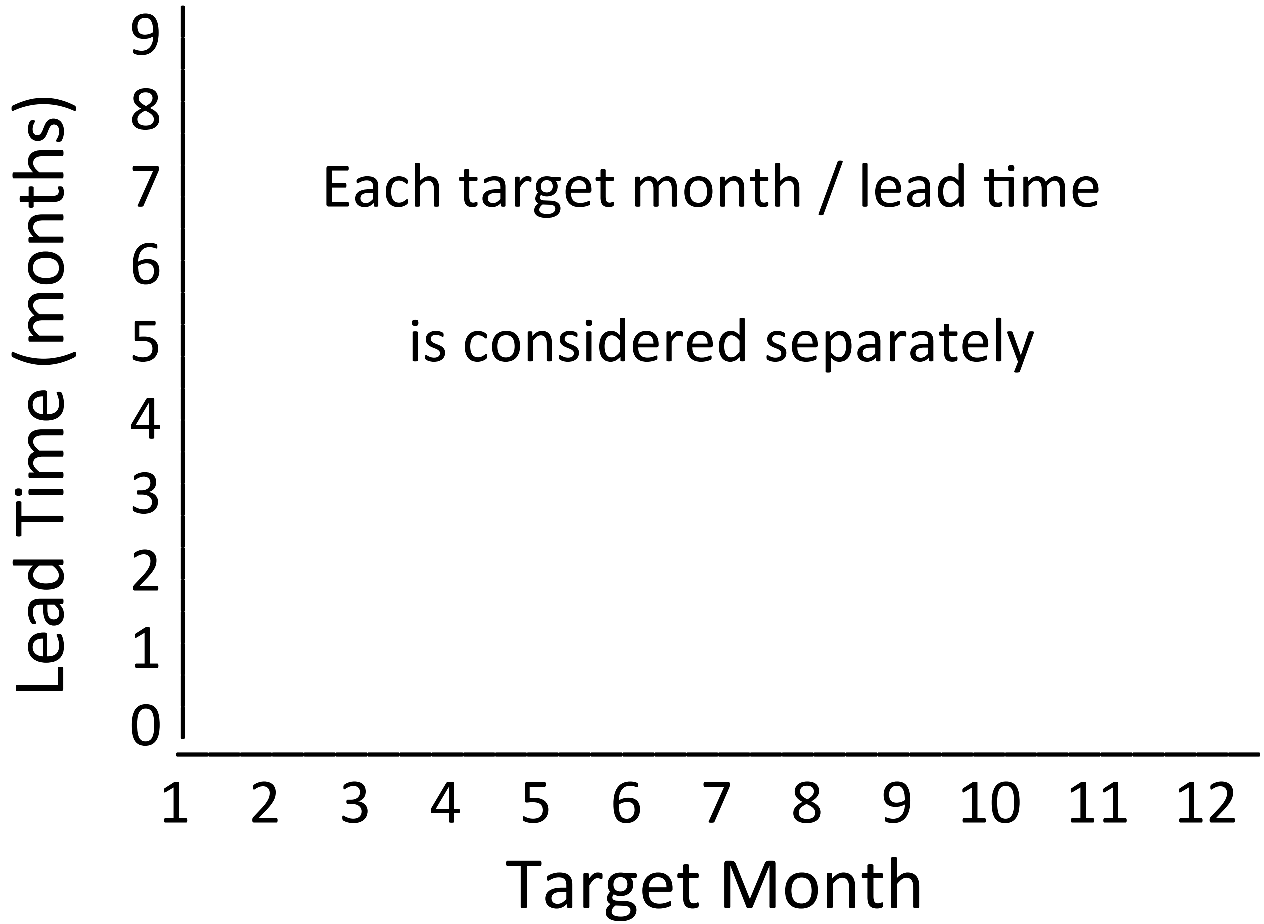
2. Correction for interannual SD (forecast amplitude), based on the existing SD of ensemble mean relative to hindcast correlation with respect to obs; *this correction does not change the spread if all members given same adjustment (additive, not anomaly-multiplicative).*

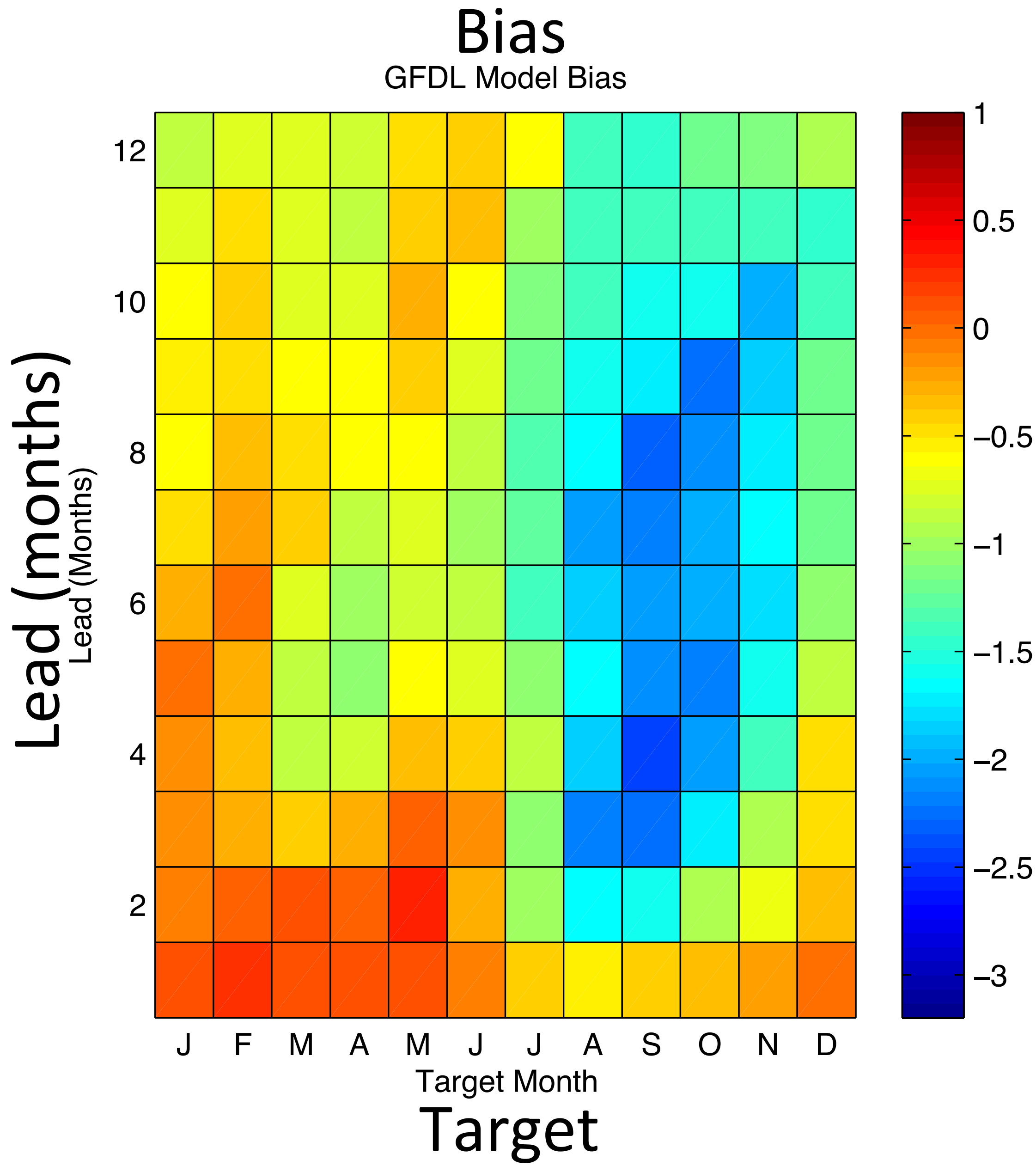
3. Correction of spread, based on ensemble mean hindcast correl with obs

--Amplitude correction is in keeping with a linear regression model, based on correlation of ensemble mean hindcast with obs.
--Spread correction sets the model S/N ratio to match that implied by correl of ensemble mean hindcasts with obs:

$$S/N = \frac{cor^2}{1 - cor^2} = \frac{\mathrm{variance(explained)}}{\mathrm{variance(unexplaned)}}$$

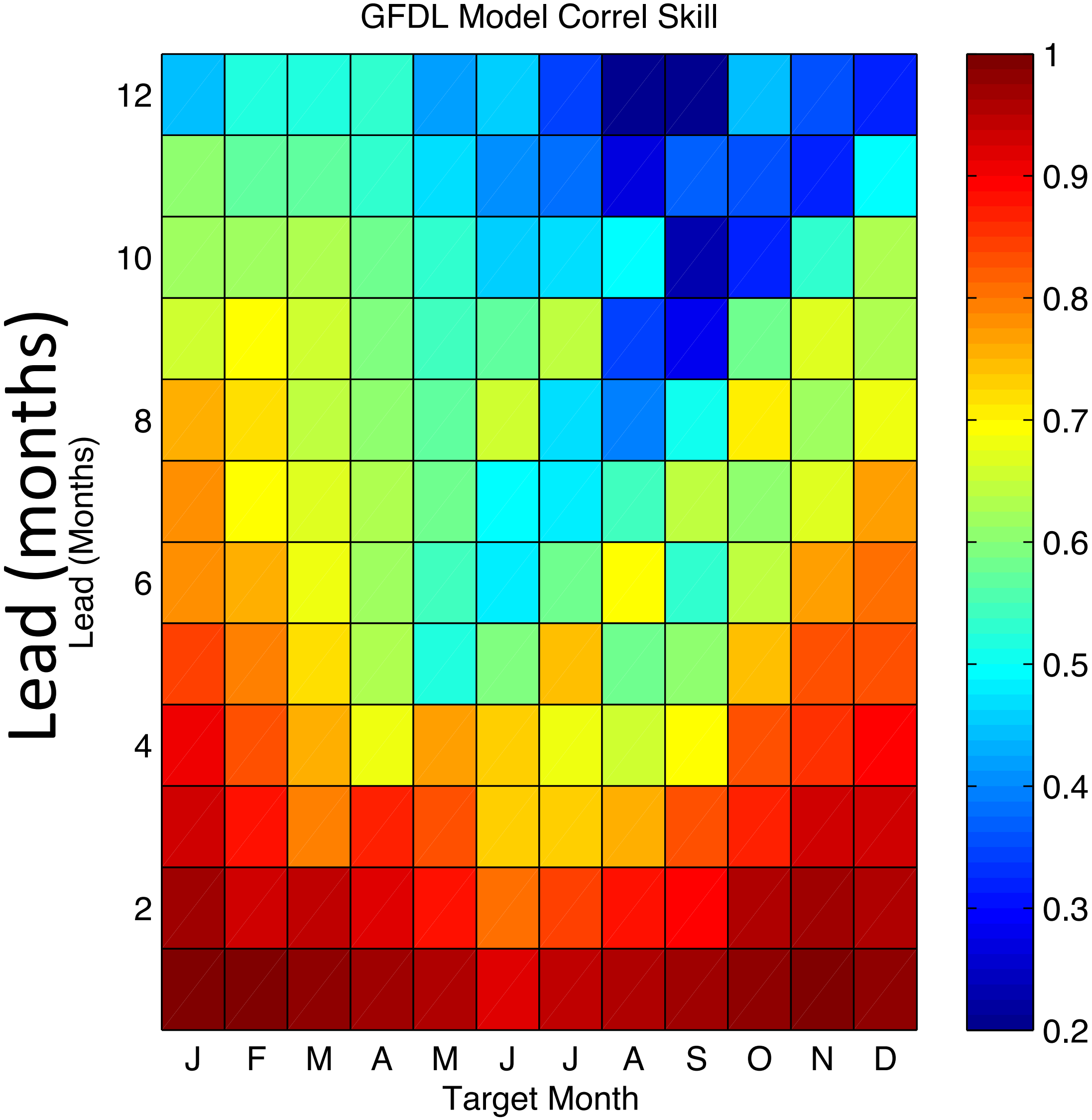
Example of bias corrections in forecasts of Nino3.4 SST by **GFDL-CM2.2** model





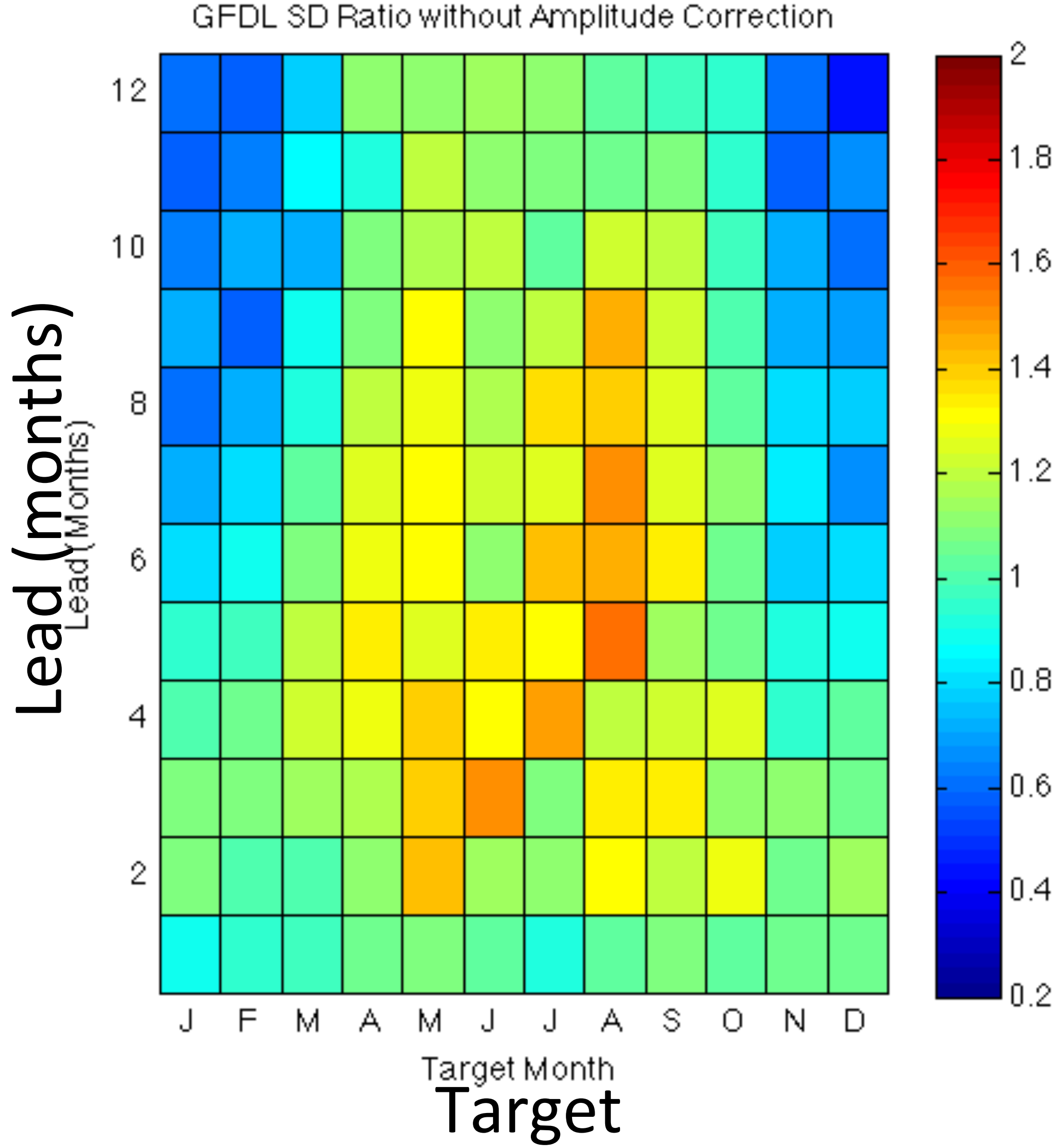
Bias
GFDL Model Bias
Lead (months)
Lead (Months)
12
10
8
6
4
2
J
F
M
A
M
J
J
A
S
O
N
D
Target Month
Target
1
0.5
0
−0.5
−1
−1.5
−2
−2.5
−3

Correlation Skill

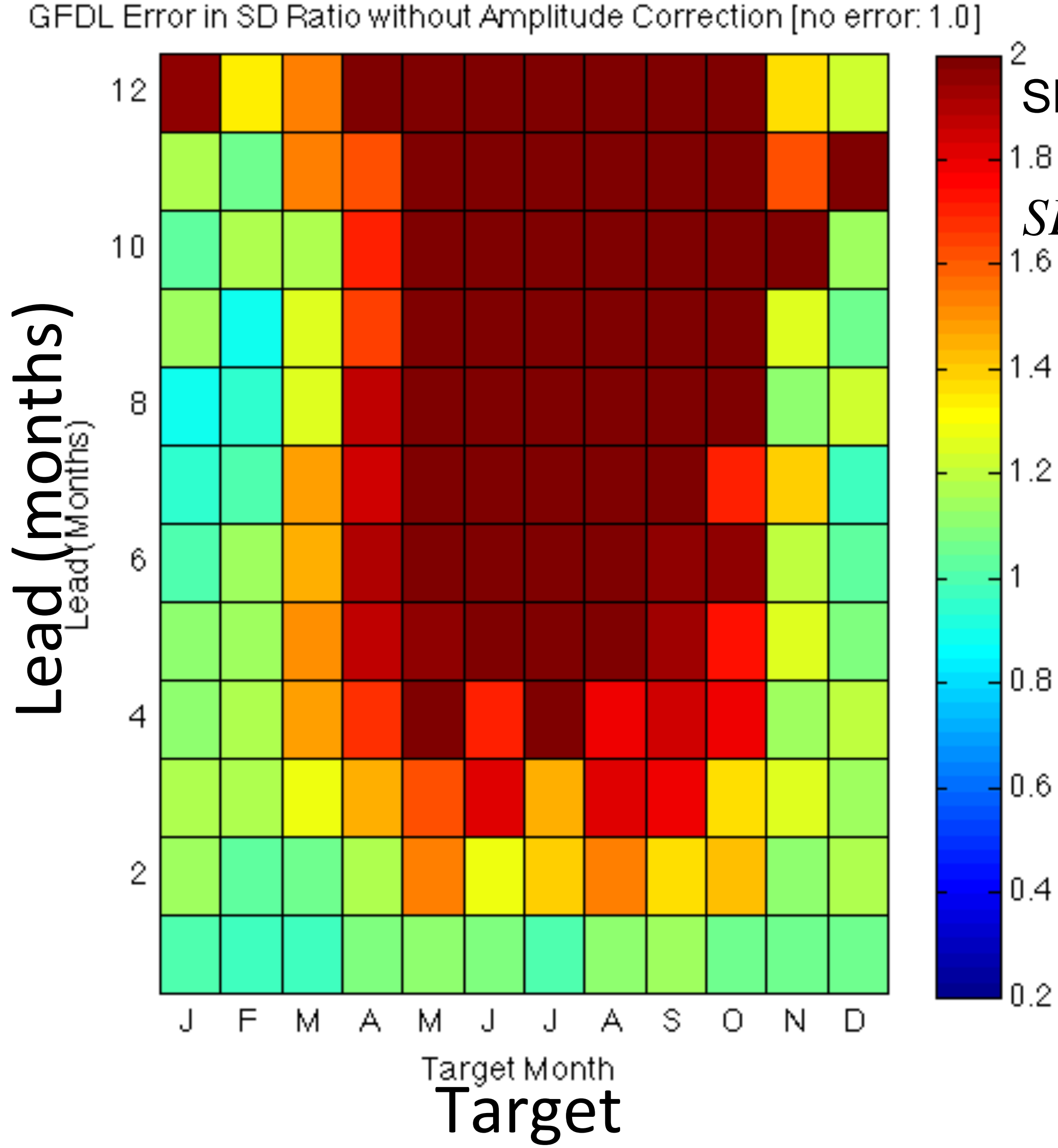


Target

SD Ratio of ens mean forecast w.r.t. Observations



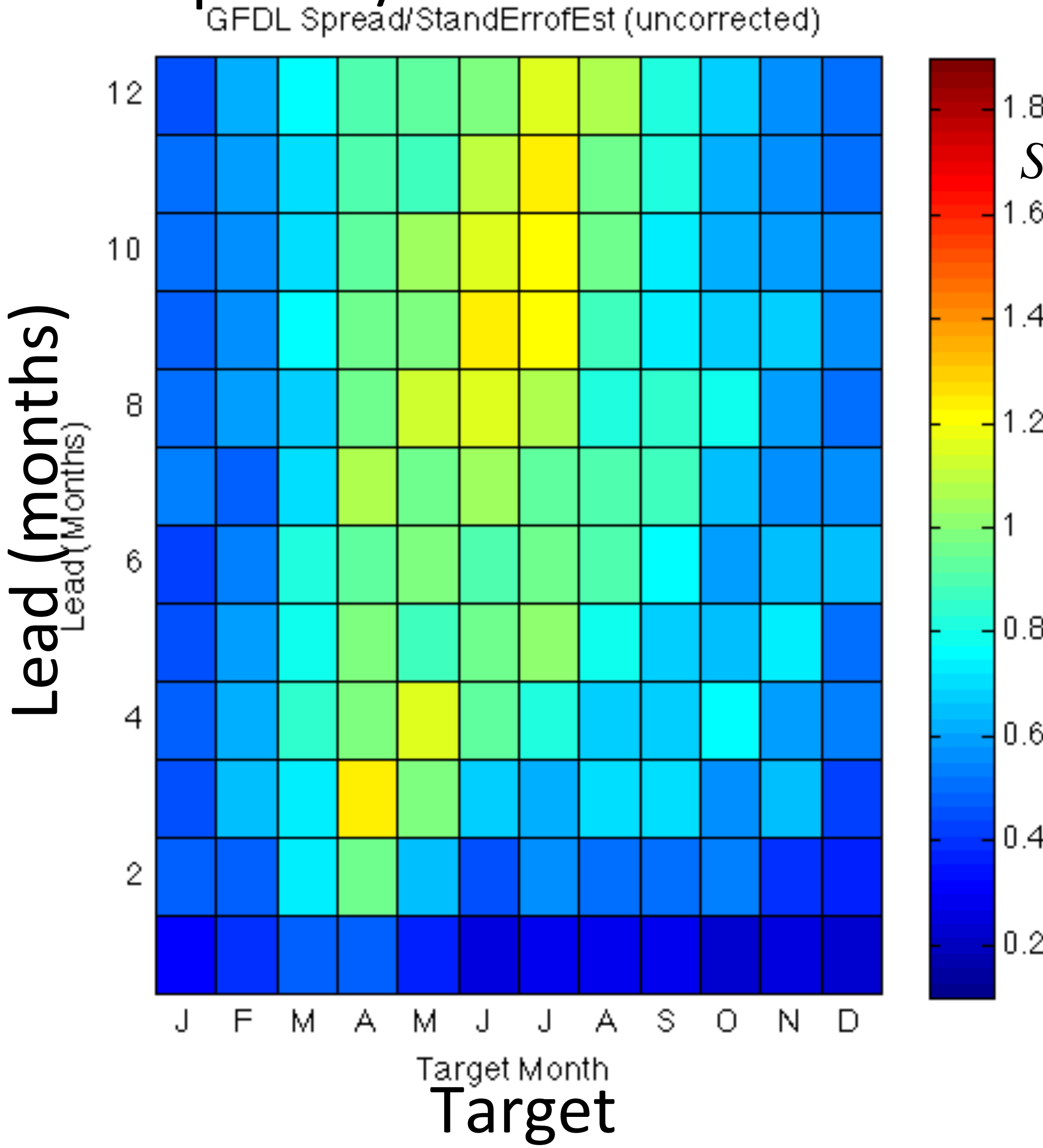
Ratio of SD Ratio to "Correct" SD Ratio



SD_{fct} = (cor) (SD_{obs})

$$SEE = SD_{obs}\sqrt{1 - cor}$$

Spread / Std. Error of Est.



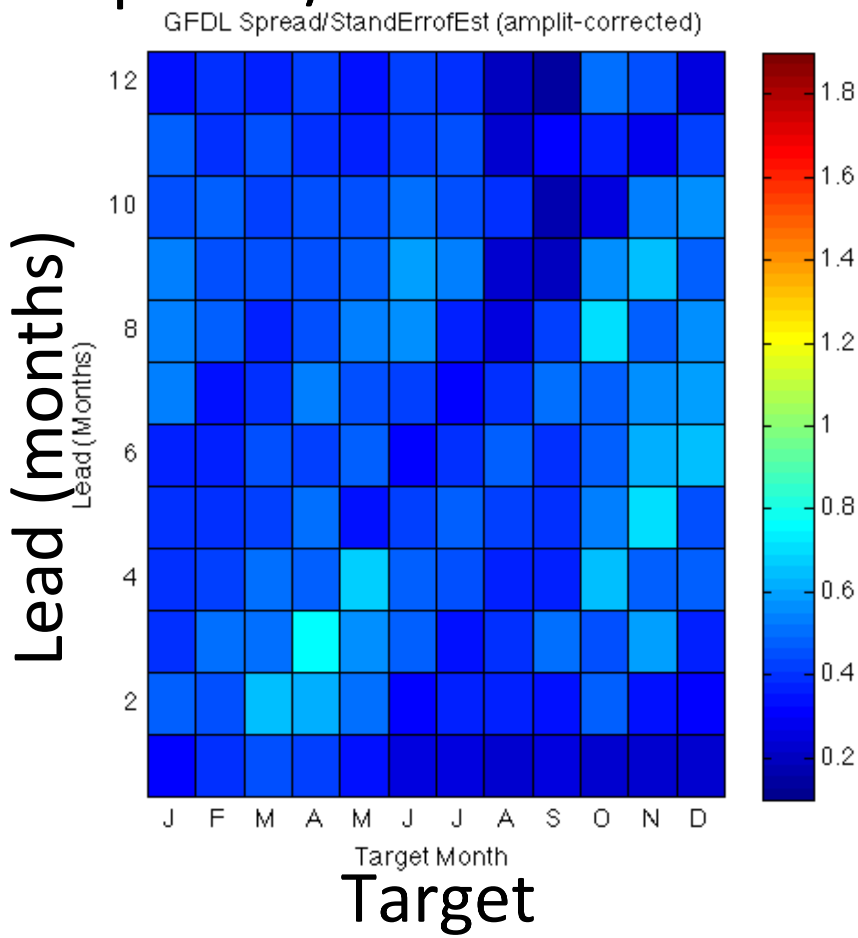
$$SEE = SD_{obs}\sqrt{1-cor}$$

Spread / Std. Error of Est. after amplitude correction, when apply ens. mean SD correction to all members in an anomaly-multiplicative fashion

$$SEE = SD_{obs}\sqrt{1 - cor}$$

Individual member corrections accompanying ens. mean amplitude corrections should retain member SD, but adjust to new ens. mean (additive).

Spread / Std. Error of Est.



Philosophic Issue with Local Bias Correction

Do we want to enforce the linear regression optimization on a nonlinear dynamical climate model? Maybe so, if seasonal climate is nearly linear. In low skill situations, many models tend to have too high an ensemble mean forecast amplitude, and too tight a spread. They behave as if uncertainty is less than it actually is.

Beneficial consequences of mean and amplitude correction:

- RMSE is minimized
- Probabilistic reliability is maximized

Pattern Correction using Linear Multivariate Linear Methods: CCA, MCA, … based on hindcasts vs obs

Uses coupled patterns of model forecasts vs. obs.

Usually is applied to the ensemble mean model forecast.

Result: When model predicts pattern A, it should be corrected to pattern B. One or more modes of such pattern correction is done. Cross-validation can be used to determine truncation point for mode number.

Pattern correction includes the local corrections for mean bias and amplitude bias, but not spread bias.

Issue with Global Pattern Correction

When done on global scale, possibilities for regional correction are often compromised (they appear on higher-order modes). Often only 1 to 3 global modes are used for correction.

Conclusion

Local and/or pattern corrections to model forecasts are desirable to make the forecasts more skillful and usable.

Amplitude corrections are controversial. They force the model to behave in a way that minimizes RMSE and maximizes probabilistic reliability, but remove the original "character" of the forecasts. Assumes linearity & Gaussianity.

Replacement of the spread by a Gaussian pdf (based on standard error of estimate associated with hindcast ensemble mean correlation skill) is controversial as it discards the details of the distribution of the ensemble members. Are those details meaningful (correct representations)?

Regime dependence ignored in these overall correction treatments.